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Rapid Reaction Valve – New System for Flow Control

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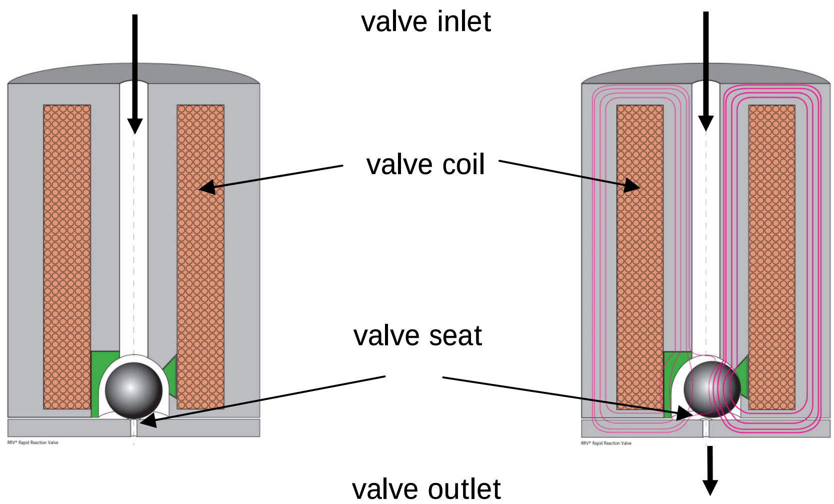
1 Introduction

In the DLR (Deutsches Zentrum für Luft- und Raumfahrt – German Aerospace Centre) a fast reacting valve for gases and liquids has been developed with promising properties for aviation and space flight applications [1]. The valve company GSR is further developing new design options of the Rapid Reaction Valve (RRV®) for industrial applications.

2 Operating Principle

The special of the valve is its operating principle. The valve is constructed in a manner, that the plug of the valve, here a valve ball, is pressed into the valve seat only by a pressure difference between the valve input and the valve output. The valve is opened by rolling the valve ball from the valve seat. The closing process is caused by the streaming of gas or liquid through the valve, which carries forward the valve ball and move it back to the valve seat.



a) valve closed b) valve open

Figure 1: Schematic drawing of a RRV®. The shape of a magnetic field line is shown.

In Figure 1 the principle set up of a RRV® in a schematic drawing is shown. The valve ball is lying on the valve seat and is kept to the seats only by the pressure difference between the valve input and the valve output. (Figure 1a)

The valve is opened by rolling the valve ball from the valve seat due to the interaction with a magnetic field which, related to the axis of the valve, lateral effects the valve ball. Therefore the valve ball must be magnetizable. (Figure 1b) In the RRV® the valve ball is the only moveable part. The rapid reacting magnetic valves can be designed to have one or several valve balls. In this paper valve with one valve ball is described.

Using the leverage effect, the valve ball is pulled from the valve seat very efficiently. The lever arm reaches from the middle of the valve ball to a contact point of the valve ball on the valve seat. By the lever action the valve ball can be moved from the valve seat by a small effort, in comparison with the effort necessary to lift up the ball upwards from the valve seat. The magnetic field acting lateral on the valve ball is caused by a coil surrounding the valve. The flux is guided in a magnetic circuit made of magnetizable materials which shows a gap made of a non magnetizable material on the same level as the middle of the valve ball. The non magnetizable material guides the magnetic flux through the magnetizable ball and creates force acting on the valve ball. To close the valve, the valve ball has to be reliably carried back to the valve seat by the streaming, which is achieved by limiting the free space where the valve ball can be moved, which keeps it close to its respective valve seat, in areas with high streaming velocities.

The streaming of gaseous or liquid media transports the valve ball back to the valve seat. With high viscose media friction forces are the dominant forces acting on the ball. In case of low viscose media high streaming velocities next to the ball, close by the valve seat, generate pressure differences which moves the ball. The liquid media can be cryogenic liquefied gases like liquid oxygen or liquid hydrogen.

3 Valve Design and Futures

The magnetic force acting on the valve ball is calculated from the magnetic force density:

$$\begin{aligned}&\vec{f} = -\left(\vec{H}\right)^2 .grad\mu\\&\vec{H} \to \text{magnetic auxiliary field strength}\\&\mu \to \text{magnetic permeability}\end{aligned} :$$

Based on the formula of the magnetic force becomes clear, a small gap width between the valve ball and the inside wall is required to reach high magnetic auxiliary field strength $\vec{H}$ with a given current through the coil. The calculated distribution of the absolute value of the magnetic field strength in the magnetic circuit of the rapid reacting valve is shown in Figure 2.

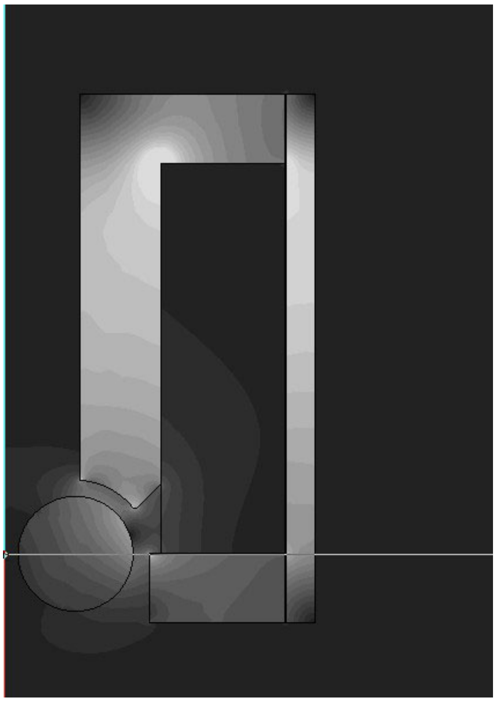


Figure 2: Model of the magnetic circuit of the RRV®. The qualitative distribution of the value of the magnetic field B was calculated and shown as grey levels. The lighter the grey level the stronger the magnetic field strength.

The pressure difference between the valve input and the valve output, the diameter of the valve seat and the diameter of the valve ball determines the force necessary to roll the valve ball from the valve seat. In Figure 3, related to the rapid reacting magnetic valve type 250 the minimum necessary electrical power input of the magnet coil, to open the valve, is shown as function of the pressure difference. A linear relation between the pressure difference and the power consumption is visible, in agreement with the mentioned formula of the magnetic force density. The value of the auxiliary magnetic field strength is proportional to the square root of the electrical power consumption of the magnet coil, and therefore the magnetic force density proportional to the electrical power consumption. The simple relation between the pressure difference and the minimum necessary electrical power to open the valve can be used to measure pressure differences with the rapid reacting magnetic valve.

With the assumption, that, related to Figure 1, the mentioned gap in the magnetic circuit of the valve is not changed, a doubling of the length of the magnetic coil halves the necessary electrical power consumption to open the valve. This is a result of the fact that a doubling of the length of the magnet coil halves the necessary current intensity through the magnet coil, the ohmic resistance doubles and due to the fact that the electrical power is proportional to the square of the current intensity the necessary electrical power halves.

This consideration is true if the magnetic permeability of the magnetizable material in the magnetic circuit is very high if compared with the non magnetizable material and the magnetic stray losses can be neglected. Therefore there is a connection between the minimum electrical power to open the valve and the dimension of the valve, which has to be considered in the construction of rapid reacting magnetic valves for aviation and space flight applications.

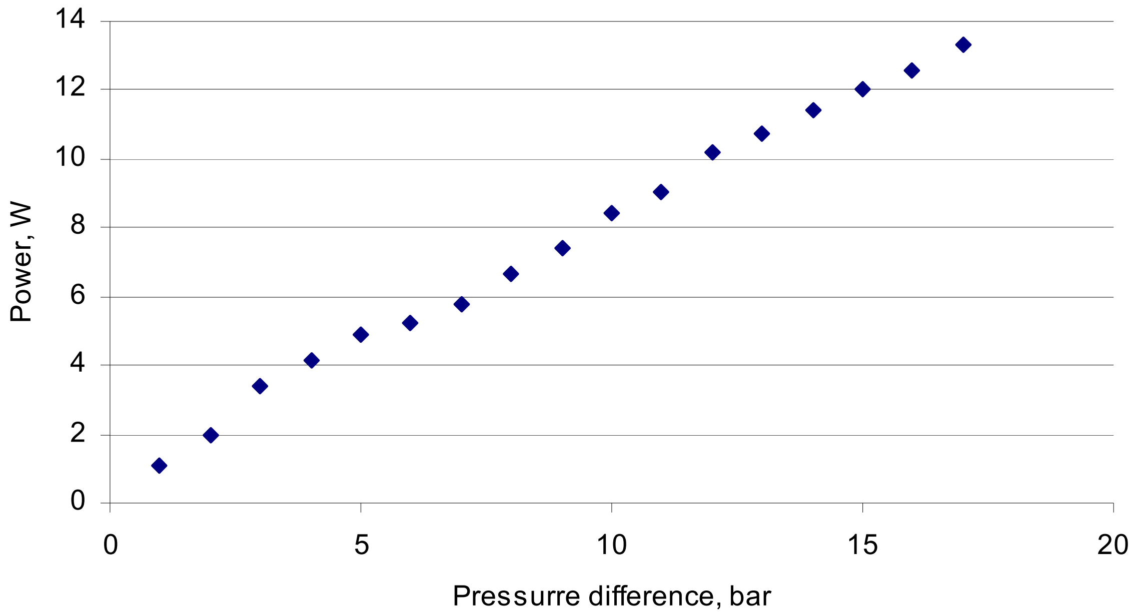


Figure 3: Relation of the minimum necessary electrical power to open the RRV® 250 as function of the pressure difference.

A compact and therefore also light magnetic valve has higher electrical power consumption.

With the rapid reacting magnetic valve gas pulses (nitrogen) were generated and measured with a hot wire anemometer, to investigate the switching properties of the valve. The wire of the hot wire anemometer was connected to a constant current source and the resistance changes of the wire, a consequence of temperature changes due to the streaming, measured. In Figure 4 a result of these measurements is shown. The magnet coil was driven by a rectangular voltage pulse marked with S: frequency 500 Hz, duty cycle 40%. Marked with H, the voltage drop over the hot wire as function of the time is shown. It becomes clear from Figure 4, that the rapid reacting magnetic valves does not opens simultaneously with the increase of the voltage S, a time delay of approximately 2.5 [ms] was observed.

The time delay is a consequence of the inductivity of the coil, which delays the current increase in the coil and therefore also the magnetic field generation, which can clearly be shortened by an as low as possible inductivity of the coil and an increased starting voltage. The valve closes immediately with the switch down of the voltage supply of the coil, here only a small time delay (<1 ms) can be observed. With the RRV® , gas pulses with frequency up to 1000 Hz were generated in the laboratory.

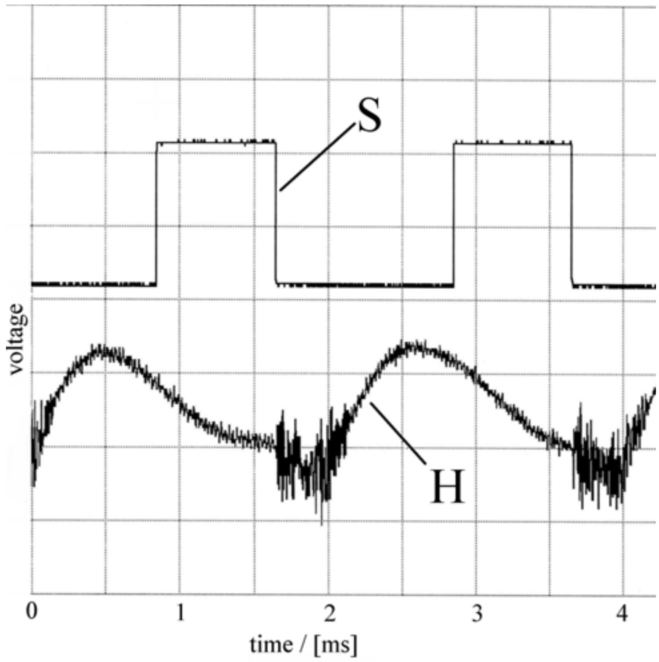


Figure 4: Switching properties of a RRV® The voltage on the magnet coil S and the voltage measured on the hot wire H is shown as function of the time. Switching frequency: 500 Hz, duty cycle: 40%.

4 Conclusion

Modern designs of gas turbines burning chambers [2] are driven, if possible, with a meagre fuel/ air mixture in the primary zone of the combustion to reduce the emission of pollutants; this applies for the aviation gas turbine as well as for the stationary gas turbine. The meagre and even more the meagre premixed burning in a combustion chamber are susceptible for burning vibrations. We can observe therefore, on the manufacturer side of gas turbines, a tremendous interest in devices and techniques to damp these vibrations. However the fast response of the RRV®, the “clean” internal design and a high life time makes the valve appropriate not only for the aerospace applications. Fast response and appropriate dosing is required in industrial and other research applications as well. For example the University of Bonn, Germany uses the valve for dosing and injection of pesticides [5,6] on the field sprayer, the research center in Jülich, Germany uses the valve for injection of fuels in the kerosene reformer for hydrogen production [3,4] and the company Materflex BZ is for almost two years successfully testing the valve for dosing of hydrogen in the fuel cell. Other applications where further tested in the pharmaceutical, food and engineering industry. Here the Rapid Reaction Valve developed by DLR and GSR can make a contribution.

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